Response to the Notice of Inquiry in the Matter of

Advanced Television Systems
and their impact on the
Existing Television Broadcasting Service

MM Docket No. 87-268

Submitted to the Federal Communications Commission
by

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November 17, 1987

*The opinions in this document are those of the author only.*

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Table of Contents

ADVANCED TELEVISION RESEARCH PROGRAM

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Federal Communications Commission
Office of the Secretary

November 17, 1987

Federal Communications Commissions
Washington, DC 20554

Gentlemen:

Attached is my formal submission in connection with the Notice of Inquiry issued August 20, 1987 in the matter of Advanced Television Systems and their Effect on the Existing Broadcast Service.

The Commission will note that I believe that the basic issue in this matter is economic, and not simply how to get beautiful TV pictures. Furthermore, the economic effects extend far beyond the TV industry. Some of the issues addressed are not those usually considered by the Commission. I urge the Commission to consult with other organs of the government, which are concerned with such matters, so that decisions can be arrived at in the best interests of the country as a whole.

This Inquiry is very timely. Great changes in TV are on the horizon. TV may develop in the US according to a number of possible scenarios, likely to have quite different effects. Since replacing the entire TV plant may well cost more than $100 billion, these effects will be very large.

Although everyone is deeply impressed with the pictures produced by the Japanese HDTV system, the plain fact is that the image quality of the existing NTSC system is good enough for its present purposes. It is most unlikely that the social role of television will be changed in any significant way by better pictures, whether provided by the Japanese system or by any of the other systems demonstrated or under development. Thus, HDTV is primarily about jobs and money, not about picture quality.

If the US takes no action to guide the deployment of ATV, it will develop according to NHK's carefully thought-out plan, backed by a large investment of money and resources. Quite properly, this plan is in accord with Japanese economic priorities. It involves, in the first instance, bypassing existing delivery systems, and, eventually, turning free TV into a second-class service. American manufacturers are likely to be entirely excluded from participation. There is no reason why we must accept this arrangement.



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I have made a series of recommendations designed to permit ATV to develop more in accordance with our own needs. These provide for a period of experimentation with a variety of new systems. The goal is a TV system that meets the needs of the American people, as expressed in their buying decisions, and at the same time delivers maximum picture and sound quality for whatever spectrum is employed. At all times, the present and future investment of both public and industry is protected. Existing broadcasters and American manufacturers have full opportunity for participation, although foreign manufacturers are certainly not excluded.

Two specific steps are proposed to prevent these goals from being derailed by the premature development of a *de facto* standard based on the sales of a relatively small number of special-purpose receivers used for playback from HDTV recordings. The first step is the abandonment of US support for the adoption of the NHK system as a *de jure* international standard for production and program exchange. Such support is not in our interest at the present time. The second is the establishment of a requirement that all ATV receivers sold in the US be compatible with a range of ATV systems likely to be provided by US manufacturers. This requirement, in my opinion, is entirely reasonable and is also technically and economically feasible.

The technological opinions expressed herein are based on many years' experience in imaging systems as a teacher, research worker, engineer, and system designer. These opinions are tempered by concerns I have had for some time about the state of American technology and the general issue of competitiveness. Since June 1983, I have been director of MIT's Advanced Television Research Program, which has been intensively studying many of the issues relevant to the Inquiry. During this period, I have had the opportunity to become familiar with the state of the TV industry and the views of many of its leaders. The judgments and opinions expressed herein are mine only, however.

In order that my submission will be of maximum usefulness to the Commission, I shall briefly describe the various documents. Document 2 gives specific replies to questions raised in the Notice. Supporting material comprises the several papers in Document 4. These include a quantification and comparison of the performance of many proposed ATV systems (4.2), two technical articles reviewing the fundamental technology (4.4 and 4.5), a technical article describing the principles of bandwidth-efficient systems, both compatible and noncompatible (4.3), and an article intended to make the technology understandable to educated laymen (4.6). There is also some information about the MIT TV research program, and a copy of my recent testimony before the House Subcommittee on Telecommunications and Finance.

The main argument is in Document 3. In this article, I have described the origins of the present controversy, discussed the contending systems, and predicted the effect of various scenarios on the principal actors involved. I have stressed the probable economic consequences and dealt with how to protect the current and future investment of public and industry. Finally, I have proposed a plan by means of which ATV can develop in an orderly manner, and suggested specific steps that can be taken to guide this development, while allowing full play to market forces.

At some time, the Commission may wish to visit MIT to see the work we have been doing. With the concurrence of our sponsors, our computer-based simulation system and Audience Research Facility might be made available for tests that the Commission may wish to carry out.

Very truly yours,

William F. Schreiber

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Advanced Television Systems
and their Impact on the
Existing Television Service

*Document 2: Replies to Specific Questions in the NOI*

William F. Schreiber

Many of the questions are discussed in Document 3 and in the supporting documents. Citations in italics at the end of each section refer to other documents in this submission. The opinions in this section are those of the author only.

1. Criteria for comparison of ATV systems

The basic *technical* performance parameters of all electronic imaging systems are spatiotemporal frequency response, bandwidth, signal-to-noise ratio (SNR), tone reproduction, and color reproduction. As applied specifically to ATV, we can speak of resolution in fixed and moving areas for both luminance and chrominance, quality of motion reproduction, and performance in the face of ordinary analog channel defects such as multipath transmission and poor SNR. From the standpoint of efficient use of spectrum, the single most important parameter is image quality per unit bandwidth. Nearly all parameters are subject to trade-off, but the proper trade-off depends on the subject matter. For example, fast-moving sports scenes should emphasize temporal resolution while slow-moving long shots require high spatial resolution. No existing systems can adapt themselves in this manner, but such adaptation is possible, at least in principle, in systems as described in Doc. 4.3. For nonadaptive systems, I would suggest using tradeoffs similar to that in 24-fps film, which is widely accepted as a standard of quality. Film stresses spatial resolution over temporal resolution.

With respect to compatibility, a method of assessment once proposed by CBS was in terms of the cost of a converter, $500 corresponding to 0% compatibility and $0 corresponding to 100% compatibility. In ATV systems, we also have to take account of degradation to images on standard receivers due to the modification of the NTSC signal as may be required for improved reception on special receivers.

An important criterion not mentioned here would be the degree to which the receivers of the various systems are compatible with other proposed ATV methods, and the extent to which they can be modified or upgraded in the field to accept evolutionary improvements in studio signal-processing techniques. A closely related matter is the extent to which the system can be used in a practical strategy to move toward the eventual abandonment of NTSC. Another important question is the cost and quality of transcoding, since any new system must be transcoded to NTSC and PAL.

Another important criterion not mentioned is the degree to which the system, and especially the receiver, takes advantage of modern technology in the form of storage and processing chips, adaptive techniques, and tailoring of system characteristics to the properties of the human visual system. Systems that do have these features are likely to work better now and

also to have much more scope for cost reduction and quality improvement in the future. Any ATV system that does *not* use frame stores in the receiver, for example, would go the bottom of my list.

Generally speaking, any audio system can be used in any imaging system, so I would propose separate evaluation of the audio and video aspects of any proposal.

*All of these points are discussed in Docs. 3, 4.2-6.*

2. New ATV Technologies

I am confident that HDTV within 6 MHz, but not compatible with standard receivers, will be shown to be practical within the next several years. "No apparent loss of quality" does not seem to me to be an appropriate criterion, however. I suggest that a desirable system is one that achieves maximum possible perceived quality for whatever transmission bandwidth it uses. This quality may well be below that of the studio standard. Naturally, all systems can give better quality if they use more bandwidth. The tradeoff between bandwidth and quality is thus an economic one. If the quality we now see in well projected 35mm movies can be reached in the home, that should be adequate, at least to start with. Using motion compensation, we should eventually be able to get spatial resolution as good as, and motion rendition better than, film. The ultimate quality than will be achievable within 6 MHz will prove to be a function of the complexity that we can afford to put in the receiver. Recent progress in semiconductor technology should make us very optimistic on this point. *The methods of doing this are discussed specifically in Doc. 4.3, with background information in 4.4-6.*

With respect to digital systems, digital coding of TV signals is much further advanced than analog coding; the missing link is the path to the home receiver. When and if this is provided by the telephone companies with fiber optic cables, the transmission problem for HDTV will disappear, at least in the cities. It will then be worthwhile to design the required chips. Most of the cost of the receiver will still be in the display device, audio output system, and cabinet, as it is in any HDTV system.

3. Time Scale for ATV

This is entirely a question of the money and effort that will be devoted to the development of new TV systems. The already developed NHK studio equipment could readily be modified to work with nearly any other studio standard, so the initial development of cameras, recorders, and displays does not have to be done over again. As for the systems themselves, as distinct from the hardware, we have spent about $3 million in the first four years of our MIT program. With extra funding from HBO, and if we can find a willing receiver manufacturer, I think we can have a 6-MHz HDTV system for cable use in the field, for limited programming from film, in about 3 years. We have also proposed a 6-MHz receiver-compatible system that would use the same receivers as the cable system. Developing the studio equipment for that system could probably also be done in the same time frame, with adequate investment. Both proposed systems are to be fully simulated within the current academic year.

4. Relative Costs of Various ATV Systems

The costs of cameras, recorders, film scanners, effects machines, and studio equipment in general, should be nearly independent of the particular studio standard. Transcoding costs do depend on the relationship of the studio standard to the various transmissions standards, with progressively scanned systems having lower costs that interlaced systems. The costs to produce programs should also not depend much on which studio standard is used.

For broadcasters, the single-channel systems that do not require transmitter modifications are relatively cheap. The 2-channel systems require a second transmitter, and the contiguous-band 9- and 12-MHz systems require either a new transmitter or extensive modifications to an existing transmitter. Studio costs are about the same for all systems.

The main investment, by far, for any new TV system is in the receivers. The cost to consumers is extensively discussed in Doc. 3 and also in 4.3. In my opinion, this is one of the most important aspects of any new system.

5. Pros and Cons of Augmentation Channels

In the long run, it is hard to see any advantage at all in using additional channels for ATV. In the interim, the 2-channel approach is one way to get perfect receiver compatibility if the signal in the main channel is unaltered NTSC. In that case, however, the basic inefficiency of NTSC also remains unaltered. As a permanent solution, such schemes will therefore always use more bandwidth than necessary.

As for the bandwidth of the augmentation channel, it should be noted that true HDTV requires about 5 times as many picture samples per second as NTSC. The augmentation channel therefore *must* use some form of compression. Glenn's proposal uses only 1/2 channel, but it does this by reducing the frame rate of detail information to only 7.5 fps, and it definitely has not be shown that this is adequate. A 6-MHz augmentation channel, such as proposed by Philips, certainly could be made to work, although that particular scheme has not yet been adequately proved out.

The likelihood that 2-channel systems will work properly under actual operating conditions is surely higher with contiguous channels. The Philips scheme uses rather sophisticated techniques to achieve good results with noncontiguous channels, but they have not yet been demonstrated to be sufficiently robust in real channels. This question cannot be answered definitively at present.

6. ATV to be UHF only or both UHF and VHF?

I am not an expert in allocation issues. As an engineer, my assumption is that the present rules are somewhat outdated, and that it would be worthwhile to do a large-scale study of this issue on its merits, independently of the ATV issue. It is highly probable that such a study would show that more channels could be made available without significantly degrading the service. From experience in Cambridge, where UHF reception seems to be better (less multipath) than VHF, the reverse of what I am told is the situation elsewhere, I see no reason why ATV should not be implemented in both spectral regions.

7-14. No comment.

15. Again, as an engineer not involved in allocation issues, band-sharing seems like an idea that can be tested to see how well it works. I doubt that there are any *principles* from which one could decide the outcome. It would seem an empirical issue.

16-19. No comment.

20-21. Taboos and Receiver Design

There is no question but that receivers can be designed and economically produced that would offer improved performance in the face of relaxation of adjacent-channel interference, and that more expensive antennas would offer improved rejection of co-channel interference. The concern would be with existing receivers and antennas, and not with new ones. It should be borne in mind that ATV systems that use a more complex signal configuration, for example by adding augmentation signals within the main NTSC channel, are inherently more subject to degraded performance on account of interference.

Setting receiver standards that are related to taboo relaxation seems to me, as a citizen, to be highly desirable. Government decisions that favor the overall good, as long as they do not unduly penalize the few, are made routinely. If it proved possible to get significantly more channels by taboo relaxation, and that required a very small percentage of viewers to replace or upgrade their receivers and/or antennas, that action should be taken. If it turns out that severe losses would be suffered by a small group, some form of compensation might be considered.

22-23. Effect of Nonbroadcast ATV on Terrestrial Broadcasters.

This issue is discussed at length in Doc. 3. Briefly, loss of audience share by terrestrial broadcasters (and local cable companies) to recorded ATV is seen by them as very threatening. These distributors do not want to go the way of AM radio, which apparently is the intention of NHK. If it developed that a significant portion of the audience, particularly the upscale viewers, were to defect to nonbroadcast delivery systems, then advertising support, which pays for programming, would diminish. For better or worse, a very large proportion of Americans, particularly those at the bottom of the economic ladder, are dependent on "free" TV for most of their news and entertainment, and some of their education. There is, therefore, a legitimate government interest in preserving the health of terrestrial broadcasting.

There is, of course, an alternative. Government itself could supply "free" TV, as is done in many other countries. In that case, nonbroadcast ATV could be allowed free reign, with no effect at all on the services available to the public. This path is not acceptable in the US. As long as we rely on advertising-supported television to provide the bulk of free services to the public, then government would seem to have the obligation to protect this medium from damage that might be inflicted by a totally free market.

24-25. Non-ATV use of Additional Channel Capacity

Speaking as a citizen, and not an engineer, I believe that there is a strong public interest in providing the same kind of free TV services all over the country. Extra channels intended for ATV ought to be used for ATV, and not for simply enhancing the profitability of licensees. Presumably, entities become licensees on the basis of their intention to provide service to the public.

26. Interference Issues

Assuming that we are not ready to relinquish all regulation of TV transmissions, I would suggest that deviations from established interference rules be permitted by the Commission, on a case-by-case basis, with adequate input from the affected community, including the public. Allowing licensees to negotiate relaxation arrangements privately seems to me to be inviting abuse.

28-29. No comment.

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Response to other requests for comments in the NOI.

Para. 41. Quick Ruling on Spectrum for ATV

In my view, the information on which a ruling could properly be based is not now available. It has not yet been demonstrated how much bandwidth is required for any particular quality level. Any ruling made at this time therefore has a certain element of risk. In Doc. 3, I have proposed a plan by which such information could be gathered in an period of experimentation that might last as much as 3 years.

Para. 42-43. ATV Integrated with NTSC or Separate?

A very important issue is whether NTSC is ultimately to be replaced, as this affects the desirability of various ways of dealing with ATV in the initial stages. Any early decision on this matter would have to be quite arbitrary. This issue is also dealt with in Doc. 3.

Para 83-86. Receiver Compatibility

As discussed in Doc. 3, the essential issue is to avoid premature obsolescence of receivers *and VCR's* now in the hands of the public, as well as those that they may be persuaded to buy as ATV starts up. Compatibility is simply one way of dealing with this requirement. Excessive reliance on backward compatibility creates a substantial impediment to the development of new bandwidth-efficient systems.

In Doc. 3, I have proposed a scheme for dealing with this question. It entails a receiver-compatible "bridge" system for providing continued service to the current receiver base. Legislation and/or regulations are proposed for compatibility requirements on new ATV receivers so that a variety of ATV systems may be tried out without unduly injuring the public.

Para. 88. VCR and Receiver Standards for Nonbroadcast Applications

Precedent for government regulation in this area is provided by the requirement that receivers should accept UHF as well as VHF signals. This requirement made UHF practical, without which we would have a much worse spectrum-scarcity problem than we have now. Reasonable regulation of input and output signal formats of VCR's and receivers seems to me to be very much in the public interest. At very low cost, much better interfaces could be provided among these products as well as computers, cable systems, and, perhaps, electronic still photography equipment. As mentioned elsewhere in this response, some regulation of ATV receivers is important simply to prevent the early devlopment of a *de facto* standard, affecting broadcast television, from the presumably imminent use of MUSE recorded materials.

The actual recording format, I believe, should be left to the concerned manufacturers and users. Government regulation is best applied to the input and output signal formats of these devices.

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# Advanced Television Systems and their Impact on the Existing Television Service

*Document 3: Analysis and Recommendations*

William F. Schreiber

## Executive Summary

*In this paper, the origin of the present controversy about improved television systems is discussed. The intense concerns shown in this matter are explained in terms of the economic interests of those involved. The characteristics of the principal contending systems are quantified, and principles are proposed that might form the basis for federal decision making in this area. The probable results of adopting each of a number of possible scenarios for development are predicted. The very different economic effects of these scenarios is stressed, together with the importance of protecting current and future investment in equipment by industry and viewers. A series of recommendations is made, including abandoning US support for adoption of the NHK system as an international standard, setting goals for a final system, establishing a period of experimentation with alternatives, phasing in new systems by a staged process, and considering the guidance of development by legislating certain receiver standards.*

## 3.1 Background of the Controversy

The recent petition to the FCC for an Inquiry was occasioned by two considerations. One is the supposedly imminent introduction into the US of high-definition VCR's and receivers, which might compete with terrestrial broadcasters and cable distributors for audience share. The other is the possibility that some of the unused portions of the UHF spectrum, which might be allocated for HDTV transmissions, may be reassigned to land-mobile radio. The time to decide about the use of spectrum for this improved television service is at hand, and there is no unanimity of opinion. A lot of money is at stake.

### 3.1.1 The NHK system

In 1981, the Japan Broadcasting System (NHK) demonstrated its high-definition television system (HDTV), developed in concert with major Japanese electronics companies over a period of more than ten years. Providing images roughly equal to those of 35-mm movies, with about five times the information of present-day TV systems, it attracted immediate world-wide attention. Great praise was heaped on the development of the advanced cameras, picture tubes, and recorders. However, the system tying all these together, for the most part,[1] is a straightforward extension of existing systems, as a result of which the base bandwidth, or channel capacity, required was about five time that of a normal NTSC or PAL signal. Terrestrial transmission of such a signal would be very difficult.

The NHK system was originally intended for DBS use, but it quickly became apparent that the 30-MHz bandwidth was excessive even in that application. In 1984, a reduced-bandwidth version called MUSE was announced, requiring only one-fourth the channel capacity. This was achieved by reducing the spatial resolution by half (discarding half the picture elements in each frame in a diagonal fashion) and by reducing the transmission rate of detail information to 15 frames/sec. This produces some loss of sharpness of moving objects, but a clever interpolation method results in surprisingly little loss of resolution as compared with the wideband NHK system. However, the sophisticated signal structure is not robust under analog transmission degradations, so that MUSE cannot be used in cable or terrestrial transmission without excessive quality loss. It can successfully be recorded on tape or disk or transmitted in a single satellite transponder channel, although a somewhat higher carrier-to-noise ratio (CNR) is required at the receiver than with NTSC.

### 3.1.2 Production standards, transmission standards, and transcoding

When HDTV development started at NHK in 1970, there was no concept of production standards as distinct from transmission standards.[2] The then-existing systems all used a common standard throughout the TV chain, including camera, transmission, and display. Many productions were made on film, both as a convenience and because they may have been originally intended for theatrical use. For that reason, film is the *de facto* production and

[1] The NTSC band-sharing principle, responsible for crosstalk between luminance and chrominance, was abandoned.

[2] This idea is also absent from the comprehensive NHK Technical Monograph No. 32, issued in June 1982, except for a passing mention of lower standards for digital transmission. All the transmission experiments reported in this Monograph were of the wideband signals.

program-interchange standard at present, to the extent that there is one. MUSE was clearly an afterthought; the idea of using the wideband NHK system only as a production standard obviously developed from the fact that the wideband signal could not be transmitted. MUSE itself would not be a satisfactory production standard, not because its quality is inadequate, but because its complexity would raise the cost of production equipment.

Since NTSC, PAL, SECAM, and film are mutually incompatible, transcoding is required when programs are interchanged between systems. This is done routinely. Although there is some quality loss,[3] especially when frame rates must be changed, this appears to be entirely acceptable to viewers, and does not affect the salability of programs.

### 3.1.3 The NHK system as a production and program-interchange standard

A proposal has been made to the CCIR to adopt the NHK system as a production and program-interchange standard. This is supported by Japan and the US and by a few small countries, but vigorously opposed by all the principal 50-Hz PAL countries. Many Americans backed this proposal in the vain hope that Europe would accept it and we would then have a worldwide standard, as least for these limited purposes. In retrospect, there is little likelihood that Europe would have accepted a system that involved high cost and little benefit. The Europeans did, at first, make mainly technical objections, but when these were eventually overcome by excellent Japanese technology, fundamental European economic interests surfaced. The Europeans are now developing a 50-Hz system under the well funded Project Eureka; the proposal for a worldwide 60-Hz standard is dead, although not yet buried.

Since the NHK system was originally intended for transmission and display, it is interlaced. As a result, it is very inconvenient, although possible, to transcode either to film or to PAL or NTSC. It is advocated for, and to a limited extent, is being used for, 24 frames/sec film production. If it were to be used *only* for that purpose, it would be perverse to use anything but 24 fps, progressively scanned, i.e., without interlace. Actually, with modern methods of motion compensation, it would be possible to get excellent motion rendition in PAL or NTSC from such a 24-fps production system.[4] Furthermore, there is a very high likelihood that international agreement could be obtained for such a production system, as it would be very similar to the *de facto* film standard now in use.[5] There is no question at all that such a system would be much more attractive for film making than the NHK system. Thus we see that the NHK system has some significant defects as a production and program-interchange standard. It appears that its principal advantage over any other possible HDTV production standard is that it is available.

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[3]The motion-compensation principle that made NHK HDTV-to-PAL conversion acceptable to meticulous European TV interests, if used for NTSC-PAL conversion, would virtually eliminate quality loss, even with frame-rate-conversion. Likewise, film-to-NTSC conversion with motion compensation can give better motion rendition than seen in the theatre from the original film.

[4]In our laboratory, we have gotten good motion rendition in NTSC from only 12-fps simulated originals. While these methods are not yet developed sufficiently for routine production use, there is a very high probability that they could be developed successfully.

[5]Since the video signal from such a system is nearly identical to that from a 24-fps film scanner, no additional transcoding equipment or processing is required to obtain output in the desired format.

In view of all this, a natural question is why there is so much passion behind the adoption of the NHK system for production. My opinion is that the reason is that such a production system gives a great advantage to MUSE, with which it is directly compatible, for transmission and recording. The latter functions are where the profit lies. There is, potentially, a great deal of money to be made in HDTV, and the distribution system is the key to controlling it.

### 3.1.4 Other factors favoring the development of new TV systems at this time

Although the Japanese developments began before the most recent revolution in electronic technology, those systems, as well as some more recent competitors, will benefit greatly from progress in semiconductor technology. Fueled primarily by the needs of the computer industry, great strides have been made in memory and computation chips, both in power and cost. As a result, a degree of complexity that would have been inconceivable just a few years ago is now eminently practical in modern receivers. The most obvious example is the frame memory, which permits separating the transmission from the display standard, and eliminating image defects due to interlace. This is so important that one can say that any proposal for a new TV system is suspect that does *not* use frame memories in the receiver.

Since the NTSC system was standardized in 1953, we have also learned quite a lot about the application of visual psychophysics to TV and about the kind of signal processing that depends on that knowledge. While these ideas are used to some extent in NTSC and MUSE, other systems have now been proposed that go much further. Two ideas are particularly important. One would divide the video signal into components in somewhat the same manner as the visual system and assign channel capacity to the components in accordance with psychophysical principles. Another falls under the rubric of motion compensation, as mentioned previously in connection with frame-rate conversion. These methods permit good motion rendition at lower frame rates than now used, thus allowing higher spatial resolution within a given bandwidth. They require sophisticated signal processing at transmitter and receiver. The net result is that the channel is used more efficiently, in the sense that a higher image quality is possible within a given channel. Under conditions of spectrum scarcity, such principles are very valuable.

## 3.2 The Players

At the recent hearing of the House Subcommittee on Telecomunications and Finance, the room was packed, and many advocates of one plan or another were heard from.[6] This enormous interest was not occasioned by a sudden devotion to the aesthetics of image reproduction. There is a lot of money being made in delivering TV services, and more in store when "the benefits of Advanced Television Systems" are eventually brought to the public. Whatever government decisions are made in this field, there will be winners and losers among those present. There is nothing wrong with this, of course - it represents the ordinary working of our economic system - but it is well to keep in mind that it is primarily money that we are talking about. In the following paragraphs, I have listed some of the groups involved and their

[6]The author's testimony is given in Section 4.7 of this submission.

apparent interests in the outcome.

*TV professional equipment manufacturers.* Generally, they are willing to make any kind of equipment if they can sell it at a profit after paying whatever patent royalties may be involved. There has been some attrition in this business, notably with the closing of the historic RCA Broadcast Equipment Division, but there are still vigorous competitors, such as Ampex and Tektronix. Such companies would prefer an early standard to avoid wasted development expense. American companies are at a disadvantage with respect to NHK/MUSE products, since the Japanese manufacturers have a head start. Of course, fairly heavy product development costs are involved.

*Consumer electronics industry.* This is a $24 billion domestic market, with 85% in foreign hands. The most recent sale was that of the GE/RCA interests to Thomson CSF. Fortunately, the latter seems to be intent on keeping these activities in the US. Zenith is by far the largest remaining US manufacturer, recently criticized by Wall Street for clinging to this industry in spite of narrow profit margins. If there were a high probability of multimillion-unit sales of any kind of receiver other than MUSE, a number of American companies could enter or reenter the TV receiver market, including some computer companies. A substantial investment would be required, but proportionately less than on the part of professional equipment manufacturers. The current dollar-yen and dollar-mark ratios are very favorable for domestic manufacturers of all kinds.

*Theatrical program producers.* For programs to be shown only in theatres or also on TV, there may be a cost saving involved in using HDTV as a production medium rather than film, provided the quality is as good as 35 mm and the capital costs are not excessive. A number of production houses are now experimenting with NHK equipment, some of it loaned or rented on favorable terms. Both cost and quality are yet to be fully demonstrated. The most optimistic estimates show a 15% saving, most of it "below the line" (i.e., on equipment and expendables) but some of it "above the line" (theatrical production expenses). The latter are in dispute, as parallel-shot NTSC is often used for the same kind of savings with film production, such as instant "rushes." Transfer of film to NTSC videotape is often used to save time in postproduction, the film assembly being done automatically after editing decisions are made with the tape. In any event, with production costs rising at about 15% per year, this does not seem to be a very important argument. (Much more money can be saved by going off shore, for example.) Film quality would be improved with a 24-fps progressive system rather than NHK, but generally the movie and TV people who are now doing this work seem to be oblivious to the technical standards. They would like *some* standard, of course, just to make it easier to connect equipment. This is hardly an argument for government intervention, however, especially in view of the very small number of studios involved.[7]

*Nontheatrical program producers.* For material never to be shown on film, such as commercials, "videos," sports, news, TV entertainment shows, and educational programs,

[7]In my opinion, any kind of standardization, other than by the concerned manufacturers, constitutes an endorsement, however unintended. The need for any standardization at the present time, especially by government, seems questionable in the light of the statement by Joseph Flaherty, at the Markey hearings, that the worldwide total of production houses using the NHK system was 20, not all of which are in the US.

producing in video rather than in film is advantageous, and is often done, at present, in NTSC or PAL. Since ATV is a more expensive medium than standard video, it is very hard to see any advantage whatsoever to using it for this purpose at the present time, unless ATV transmission is anticipated at a later date. Even in that case, interest expenses during the period that the more expensive production is held for possible later use must be taken into account.

With the NHK system, it is most unlikely that higher quality NTSC would result, after transcoding, as compared with NTSC originals, even though the costs are higher. There is likewise no advantage in transcoding for program interchange, since that would now be required in every case, whether the output is NTSC, PAL, or SECAM, and is also more expensive. A video production may be somewhat less expensive than film (actually, on remote location, film is probably cheaper) but film is not required for this application anyway. Some video producers may be looking for a way to get into non-video production eventually and may see ATV as an easier way to do this than equipping themselves for, and learning, a totally new medium.

*Local distributors,* such as local TV stations and cable operators, have the most to lose from MUSE. If it is delivered by cassettes or disks, or by fiber installed and operated by the local telephone company (such as the Bell Operating Companies, BOC's, who have expressed a great deal of interest in this possibility), they are in danger of being bypassed. To the extent they are, they immediately lose market share and advertising revenue. These distributors therefore want to be able to compete by transmitting ATV in a compatible manner to reach their present viewers, preferably using only their present channels. To the extent that the local distributor also produces local programming of interest to the current viewership, he owns something that is of value in dealing with the BOC, but this is not a weapon against recorded software. MUSE or any other noncompatible system is of little interest.

*Wholesale distributors,* such as Home Box Office and the networks, buy, sell, and distribute programs for delivery to viewers by others. To the extent that they also own local distributors, they may have some of their same interests. To the extent that they also produce programs, they may have the same economic interests as other producers. As wholesalers, they are primarily motivated by the need to compete with ATV delivered by means alternative to those used by their customers. Therefore, they also prefer single-channel backward compatible systems. Cable companies are in a somewhat different position here than "free" TV interests, in that many of the programs have controlled access. In that case, a system not receivable on existing receivers may still be acceptable if the new receivers can be provided in some feasible manner.

*Alternative distributors.* Neither fiber-optic or DBS delivery systems are much used in the US at present,[8] but there is a great deal of interest. From the purely technological point of view, if we were starting to develop a plan from scratch for TV distribution in the US, fiber in the cities and DBS in the countryside could make a certain amount of sense. Both systems provide a "cleaner" channel than terrestrial or cable channels, and therefore could use MUSE. DBS would benefit from an efficient TV system in much the same manner as terrestrial and

[8]There are about 2 million TVRO (television, receive only) satellite installations in use at present, mostly in rural areas, but to some extent for hotels and similar commercial enterprises.

cable transmission. Fiber, for the most part being digital, presents other problems and opportunities beyond the scope of this paper. Suffice it to say that the bandwidth-efficient systems described in Section 4.3 of this submission are also applicable to fiber transmission. Both systems require receivers, but have less need than terrestrial broadcasting for backward compatibility. Needless to say, any substantial growth of these two media would have adverse effects on other local distributors.

*Theatre owners* would greatly prefer that TV fade away. They could be a showcase for ATV, but this would require an investment that may well be beyond the ability of many local theater owners to make. To the extent that ATV comes to the theater, it will probably speed up the trend toward well financed chains, such as USA Cinema. Unfortunately, this will further erode the viability of small "art houses," which are not seriously affected by TV at the present time. To the extent that distribution to theaters is by DBS, the same considerations with respect to standards apply here as well.

*Recorded material rental industry.* These interests are satisfied with NTSC and VHS tape and wish everything else would go away. Like the bulk of viewers, "the show's the thing." They see ATV (or any other new format, such as 8mm, and probably S-VHS) as a threat that may require defensive inventory investments that are likely to go down the drain with diminishing interest on the part of renters. If any new medium does become popular, those with adequate resources will stock it, and may make high profits if the business grows fast enough. This could be the case if MUSE tapes and disks develop into a large market, and the VHS market does not suffer thereby.

*Advertisers.* They are always looking for a new medium, but do not seem to have been heard from in this instance. They have not shown any interest in financing the development of ATV, although they will surely be happy to use it, if it has a sizable audience.

*Viewers* are overwhelmingly interested in programs, not picture quality. Of course, anyone can easily see the difference between NTSC and HDTV, and prefers the latter. It is not clear how much viewers would be willing to pay for the better picture and sound quality (the latter is more important!) with the same programs. Judging by experience with cable fees and rentals,[9] viewers would buy ATV receivers if the price were integrated with the program fee, and possibly if desirable software were available exclusively or simply earlier. Perhaps the upscale 10-20% would buy receivers just for novelty or quality. What is fairly clear is that the owners of the 140 million-plus existing receivers will not tolerate their sets being blacked out of their favorite sports and entertainment programs, to be shown only on ATV receivers.

*The public.* This is, by far, the largest affected group, and it is interested, primarily, in the economic effects, i.e., the effects on jobs, the trade (im)balance, and general prosperity. To the extent products are manufactured in the US, ATV could have a strong stimulating effect on the economy. If most ATV products are imported, the effect will be negative, particularly on the trade balance and employment. ATV is the next big step in consumer electronics, and it is therefore important to assess its likely effects in some detail before embarking on any

[9] In 1986, more money was spent on cassette rentals than on movie admissions. The public is clearly willing to spend money for programs.

particular course.

### 3.2.1 Conclusions with respect to players

In view of the large number of parties involved, and the overwhelmingly economic nature of their interests, it is clear that decisions about ATV are primarily about jobs and money, and only marginally about beautiful pictures. Some players see ATV as a threat and some as an opportunity, and to some, it doesn't make any difference. To some, which ATV system is used is important, but to others, one is as good as the other. In the long run, very few players would be harmed more by an American ATV than by a foreign one, even if the former came along later. Most, especially domestic manufacturers and the public, would be adversely affected by a foreign ATV and would benefit from an American system, mainly manufactured in the US.

The success or failure of ATV, and the magnitude of the resulting economic effects, good or bad, will depend primarily on the programs that are offered in the new medium, and whether the hardware and software costs are low enough to encourage people to use it. Success also depends on having a system attractive enough financially so that industry will make the required investment.

This emphasis on the economic aspect of ATV may seem strange to many who have been impressed primarily by its high picture quality. It is certainly true that the high definition and wide aspect ratio of the new systems make possible a somewhat different kind of program directing. There are many visual effects that fall flat on the small screen; in fact, since the final destination of most Hollywood productions is television, there has been a noticeable fall-off in the kind of blockbuster spectacles that were the hallmark of the widescreen revolution of the fifties. The idea that this difference is sufficient to spark any kind of cultural renaissance, however, seems preposterous. The social role of television is most unlikely to be changed in any important way by the advent of ATV.

## 3.3 Performance of Various Proposed ATV Systems

It is remarkably difficult to make quantitative comparisons among the various proposed ATV schemes. This is, in part, due to the fact that some have no definitive description in the literature.[10] An inherent problem is that all imaging systems consist of many stages, with the image quality affected at every stage. Although we often talk about systems in terms of the number of scan lines, and this is surely an important parameter, pictures cannot be much better than that generated by the camera and displayed by the picture tube, regardless of the scanning standards. Image quality is also adversely affected by defects of the transmission channel, especially if it is analog.

Of course, in any multistage system, it is possible, to some extent, to compensate in one stage for defects and limitations of another. There are restrictions on this process, however. For example, signal-to-noise ratio (SNR) and sharpness are two fundamental aspects of image

[10]It is fair to say that *none* is described completely and precisely.

quality. Images can be sharpened a great deal at the expense of SNR, and the SNR can be improved a great deal at the expense of sharpness. Adaptive methods developed in the graphic arts, but not yet widely used in television, can do some sharpening and some SNR improvement at the same time. In general, sharpness goes up with bandwidth, and SNR goes up with signal power, closeness to the transmitter, and size of the receiving antenna.

Another important image defect is *aliasing,* which, as its name implies, means one signal component masquerades as another and is misinterpreted. Common examples are cross color and cross luminance. In the former, fine detail luminance information is interpreted as color (artificial rainbows where they don't belong) and in the latter, color information, particularly at the edges of brightly colored objects, produces a moving crosshatch of spurious brightness detail. These defects are highly visible to experts, and can also be seen by lay viewers on side-by-side comparisons. Whether they are important by themselves is not clear. For example, TV directors usually do not even bother to advise actors to avoid check patterns on their clothing, which produce cross color.

A curious phenomenon is *motion rendition.* We all occasionally see wheels turning backward in movies, and worse effects occur when movies are shown on TV, but there is never a complaint from the audience.[11] This effect depends on frame rate and, to some extent, on temporal processing of the signals. It is *much* worse in film than in TV, because NTSC has 2.5 times the frame rate (for motion) as film. My conclusion from this is that the TV rate is too high, and that we would be better off with lower temporal and higher spatial resolution. This is exactly what is done, at least for the high-frequency component, in many ATV systems.

*Interlace* is responsible for a range of defects in today's TV systems, all of which use it to improve the tradeoff between vertical resolution and flicker. It can be eliminated by using progressive scan at the display, which usually requires a frame store.

A very important characteristic of new systems is the extent to which they can be used with existing equipment. We speak of *receiver-compatibility* (also called backward compatibility) as the ability of a system to be displayed on existing receivers without serious degradation. By *channel-compatibility,* we mean the ability to be transmitted in existing channels. This means not only that the rf bandwidth must not exceed 6 MHz, but that the signal should be reasonably resistant (robust) to normal analog channel phenomena such as multipath and low signal-to-noise ratio (SNR).

In order to make some kind of compact comparison among the various proposed systems, I have listed certain performance parameters in the following table. Spatial resolution in fixed and moving areas is calculated on a uniform basis from the available data, as is the bandwidth requirement. For the purpose of this calculation, it is assumed that the resolution is limited by the scanning standards and the bandwidth only, and that the camera and picture tube are perfect. Although this is not an entirely accurate assumption, it does not affect the relative performance of the various systems. Actual resolution reached will be smaller in all cases. As equipment improves, the resolution will rise. The other characteristics listed are judgments,

[11]Each year, in my image processing class, I train my students to see these effects. Most never have, and some never do, even after I tell them what to look for. To a sensitized viewer, such as myself, they are really spectacular and bothersome.

the bases for which are discussed in Document 4.2.

Performance of Various Advanced Television Systems

| System | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stationary-area luminance resolution | | | | | | | | | | | | | |
| Vertical | 480 | 336 | 480 | 728 | 728 | 480 | 408 | 717 | 408 | 480 | 480 | 600 | 762 |
| Horizontal | 440 | 316 | 440 | 1007 | 1007 | 550 | 874 | 1300 | 650 | 650 | 750 | 660 | 1354 |
| Diagonal | F | F | R | F | R | F | F | R | R | R | F | R | R |
| Stationary-area chrominance resolution | | | | | | | | | | | | | |
| Vertical | 480 | 336 | 120 | 717 | 520 | 120 | 240 | ? | 120 | 120 | 480 | 360 | 254 |
| Horizontal | 158* | 62 | 62 | 352* | 352 | 62 | 247 | ? | 62 | 62 | 200 | 124 | 451 |
| Diagonal | F | F | F | F | R | F | F | ? | F | F | F | F | F |
| Moving-area luminance resolution | | | | | | | | | | | | | |
| Vertical | 480 | 336 | 480 | 717 | 520 | 440 | 408 | 408 | 408 | 480 | 480 | 360 | 254 |
| Horizontal | 440 | 316 | 440 | 1007 | 629 | 316 | 494 | 441 | 316 | 316 | 750 | 316 | 451 |
| Diagonal | F | F | R | F | R | R | F | F | R | R | F | F | F |
| Moving-area Chrominance resolution | | | | | | | | | | | | | |
| Vertical | 480 | 336 | 120 | 717 | 260 | 60 | 240 | ? | 120 | 120 | 480 | 360 | 254 |
| Horizontal | 158* | 62 | 62 | 352* | 352 | 62 | 124 | ? | 62 | 62 | 200 | 62 | 451 |
| Diagonal | F | F | F | F | R | F | F | ? | F | F | F | F | F |
| Channel (rf) bandwidth, MHz | 6 | 6 | 6 | 50 | 10 | 6 | 12 | 9 | 6 | 6 | 12 | 6 | 6 |
| Compatibility (1-10) | NA | 10 | 10 | 1 | 1 | 7 | 10 | 10 | 6 | 6 | 10 | 8 | 1 |
| Receiver complexity (1-10) | NA | 1 | 5 | 5 | 10 | 8 | 6 | 7 | 6 | 7 | 6 | 10 | 10 |
| Multipath performance (1-10) | NA | 5 | 5 | 10 | 1 | 4 | ? | 5 | ? | ? | 5 | 5 | 10 |
| Low SNR performance (1-10) | NA | 8 | 10 | 10 | 5 | 7 | 8 | 8 | ? | ? | 8 | 8 | 10 |
| Cross Effects (1-10) | 0 | 2 | 7 | 10 | 10 | 8 | 7 | 7 | 10 | 10 | 7 | 9 | 10 |

Systems:

1. NTSC theoretical
2. NTSC notch filter 525/30/60
3. NTSC 2-d comb filter 1050/60/60
4. NHK wideband 1125/30/60
5. MUSE 1125/30/60
6. Fukinuki, Matsushita 1050/60/60
7. NA Philips 525/60/60
8. Glenn 1050/60/60
9. ACTV 525/60/60
10. ACTV 1050/60/60
11. Rzeszewski 1050/60/60
12. MIT-RC 1050/60/60
13. MIT-BE 1200/60/60

Notes:

A/B/C means A lines, B frames/s, C fields/s
Starred items have different resolution for the two color components
F = full, R = reduced diagonal resolution
Last five lines are qualitative judgments
All calculations subject to correction

### 3.4 Proposed Principles for Federal Involvement

In accordance with generally accepted assumptions about the appropriate functions of government, I suggest that the federal role be as small as possible, consistent with the goals of national policy and the likely behavior of corporations and individuals affected. Market forces should be relied upon to the extent possible. On the other hand, no one seriously proposes that all government regulation of radio emissions be eliminated. In fact, our treaty obligations prevent such a course of action. Since no transmissions are permitted under existing law without FCC approval and regulation, doing "nothing" means that ATV will develop solely through nonbroadcasting channels, a result that today's broadcasters believe would be extremely detrimental to their interests. Doing "everything" means deciding, in the near future, what the shape of ATV will be for many years to come, and prescribing transmission standards and spectrum allocations to support those standards. While some of the more enthusiastic supporters of one system or the other may endorse this view, most would say that such action is premature.[12]

Since the country is not yet ready to decide on a particular path into the future of television, then I propose that whatever decisions that are made be based on the following considerations:

#### 3.4.1 The long-range effect on the economy

As discussed above, the effects of ATV will be primarily economic, and, if it grows as expected, may be very large. I believe that the most important economic feature of any new system is the proportion of hardware that can be manufactured domestically. There may well be other significant economic features. In any event, some effort should be made to predict the economic results of any government decisions, and that path should be taken that is likely to produce the most desirable result from the standpoint of the whole country. Of course, such predictions cannot be completely accurate, but it does not follow that no attempt should be made to anticipate and plan for the future.

#### 3.4.2 The effect on consumers

The consumer ultimately pays for television, and in a field where government regulation is essential for any reason, these regulations should operate to advance the interests of consumers as much as feasible. Consumers have an existing investment in NTSC receivers and VCR's. No guarantee of infinite life comes with any purchase, of course, so that it is not necessary to keep NTSC transmissions forever. Any changes, however, should be gradual enough so that existing equipment may be used for a substantial part of its natural life. New equipment offered for sale, and manufactured with the blessing of the government in some form such as operating standards, should likewise be supported for a reasonable period of time. Whether the sale of equipment not built according to government standards should also be regulated is a more difficult decision, but may also be considered. Any departure from the principle of "free"

[12]At a recent SMPTE meeting, one prominent supporter of the NHK system made the statement that no standard was ever too early. After the meeting, I gave him an example - the field-sequential color standard, which I (mistakenly) supported at the time.

basic television service via low-cost receivers should be made only with great care and with the tacit approval of a very large proportion of users.

### 3.4.3 The effect on industry

As discussed above, any change in the TV industry will produce some winners and some losers. It is not generally the business of government to adjudicate competition amongst companies or amongst industries, except in the larger public interest. However, where changes in long-existing government regulations actively favor one interest over another, then great care is required. In this case, the overriding interest is that of the public. In effectively choosing winners and losers, service to the public and the effects on the economy should be the main concerns. The former involves the range and type of programming to be made available. The latter involves employment, and particularly manufacturing employment. Where there is a choice, decisions should be made that favor domestic manufacturing employment.

### 3.4.4 Spectrum conservation

Radio-frequency spectrum is a scarce[13] commodity, which is the main reason why it is regulated. (Convenience is another.) TV is, by far, the most voracious consumer of spectrum. There are many other demands, such as land-mobile radio. One principle of regulation might well be to promote the most efficient use of spectrum. The image quality achieved per unit bandwidth is therefore the single most important parameter of any proposed new system. Since this parameter depends, among other things, on the cost and complexity of receivers, there is a tradeoff between receiver cost and number of channels. It is government that must make this tradeoff. Preference should be given to systems that show promise of high efficiency with reasonable receiver cost. Since NTSC is an inefficient system, its ultimate phase-out would seem to be desirable, provided that can be accomplished with minimum adverse economic effects.

As a principle, replacing every piece of TV hardware in the country is a path to wealth, not poverty. This, after all, has been the history in many fields that ultimately have made important contributions to our economic well-being, such as the automobile industry. The problem is not the final result, which is clearly desirable. The problem is how to deal with the dislocations to individuals, companies, and industries in the process of replacing what we have with something better. If the eventual elimination of NTSC is decided on, a scheme for reaching that goal in a satisfactory manner must be thought out.

## 3.5 Possible Scenarios: Their Costs and Benefits

There are a number of different ways that ATV can come to pass in the US. Like any other kind of forecasting, there are many hazards in this prediction. Nevertheless, it is a useful exercise in that exploring some of the possibilities may provide some clues as to how to pick and

[13]This is sometimes disputed with the argument that fiber, cable, and compression techniques have effectively provided much more spectrum. Such arguments are shown to be invalid by the very existence of the current Inquiry. If there were enough freely available spectrum for both wideband HDTV and land-mobile radio, no Inquiry would have been launched.